Coalition Formation and Power Control for the Enhancement of System Performance and Resource Reuse for Device-to-Device Communication in 5G Systems

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Abstract: - Based on the specifications released by 3GPP (3rd Generation Partnership Project), we use game theory to divide (D2D) device-to-device users using the same base station into different coalitions by calculating the signal to interference noise ratio, and by controlling the transmit power, we allow the reuse of the same spectrum resources, thereby reducing the overall D2D demand for resources. By calculating the resource requirement of the pairs that have more demand in a coalition and using it as the basis for resource allocation by the base station, we can satisfy the demand of all D2D pairs in the same coalition. Therefore, the overall system performance can be enhanced. The formation of coalitions and the power control method are the focus of this paper.

Key-words: -5G, D2D (Device-to-Device) Communication, Power Control, Resource Reuse, Interference reduction, eNb (Evolved Node b), CUE (Cellular User Equipment), DUE (Device User Equipment).

1 Introduction

The concept of D2D (device to device) communication has attracted attention in next generation mobile communication. The popularity of the emerging Internet of Things coupled with the recent technologies of the fifth generation (5G) wireless network communication system in years has brought a significant change in human lifestyle. Direct communication between nearby mobile devices to share information can reduce the load on the core network. In addition, D2D can improve the reuse of resources to improve system throughput.

With the allowance of limited resources, introducing a small base station in the 5G system environment reduces the complexity in the base station. However, it also faces many different challenges, such as the need for high density, and the requirement of the device to be within a short distance. To improve the efficiency of resources, 5G communication technology introduces D2D communication technology through which the devices can communicate among themselves without the help of the base station. This has been defined in the R.8 specification version of the 3GPP (Third Generation Partnership Project). In D2D communication, the following four main aspects are considered (i) the load of the core network, (ii) the transmission of the network system, (iii) the direct transmission between the devices to reduce the transmission delay and (iv) improvement of the user experience. However, when many devices are involved, it is a challenge to determine how to allocate the resources efficiently so that the impact on individual users by the presence of neighboring devices remains minimal. Recent research on D2D focuses mainly on the development and deployment of resource allocation methods.

In this study, we present a scheme that can improve the reuse of resources. This scheme allows the reuse of the resources used by the existing CUE (Cellular User Equipment) for D2D transmission, thereby further enhancing the system performance. In the proposed method, D2D UE (DUE) forms coalitions and power control is imposed on the DUE to mitigate the effect of interference among them. Procedures for coalition formation and power control are presented. The simulation shows that the proposed method exhibits better performance than existing methods that adopt coalition formation alone.

The paper is organized as follows: Section 2 discusses the research motives and purposes; Section 3 discusses the proposed scheme and explains the coalition formation method. In section 4, the proposed power control scheme is discussed. And Section 5 discusses the simulation and results. Finally, section 6 is the conclusion of the paper.

2 Research Motives and Purposes

Both uplink and downlink CDMA systems in a communication network use power control to allocate resources. One of the main drives behind 5G is the need to increase the capacity to cope with the mobile data traffic explosion [13]. In D2D, users with a short distance and high signal-to-interference-plus-noise ratio (SINR) may communicate directly with each other without sending the information to a base station (BS). The BS only sends control signals to these users. The users use either license excused bands or licensed frequency bands. Power control can maximize the total performance of the system and minimize the total transmit power simultaneously [14].

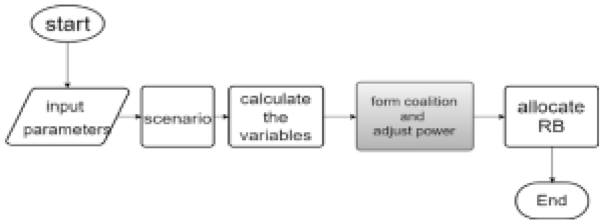
When frequency reuse is applied to improve resource utilization, the interference among macro-cell cellular links, small-cell cellular links, and D2D links should be considered and efficiently managed. Moreover, a D2D pair can be from different cells, which further complicates interference control. Therefore, it is necessary to investigate how to achieve efficient interference management [13]. To achieve the quality-of-services during transmission, power control over the transmission plays a major role. Power control must be maintained accurately so that it does not cause any interference to the other users [12], because many users are battery powered and the necessity to use an efficient power control system is an important task to extend battery life.

Currently used techniques involve only coalition formation to group the DUE to enhance performance. However, when we use power control for coalition formation, we observe that the rate of interference in the system is drastically reduced and the overall system performance of the urban macro channel mode environment is improved.

On reusing the same resources, interference between the device can cause major problems. Previous studies consider the demand for resources based on the user's perspective. In this study, we mainly focus on the use of the concept of coalition formation to D2D user sub-groups. We also use power control to reduce the interference of D2D among each other. Using different techniques, we observe and study interference management issues to allow the reuse of resources to enhance the performance of D2D users.

3 Proposed Scheme

3.1 Flowchart of the Proposed Scheme



The process begins with the proximity discovery procedure. The parameters are input to the urban macro-channel model environment. The variables are calculated using the defined parameters, followed by the formation of the coalition for users based on the power control parameters. After the coalition is formed, the resources are allocated. This study, we have formed the coalition of users by determining the power of the individual D2D pair, thus allowing the resources of the CUE to be shared with the DUE. The resource blocks are allocated through direct transmission. D2D users could improve the performance by reusing the uplink spectrum resources of the CUE. We consider the outdoor environment under an Urban Macro-channel model, with only one base station, that covers 500 meters, within which the D2D users and the cellular user are randomly distributed. But the D2D users are distributed beyond the range of 35 meters around the eNB [1] and we reuse the RB's of CUE within that area. Uplink resources of CUE are reused for D2D communication and thereby reducing the overall requirement of resources.

We split our proposed method into two parts, the first part is to calculate the SINR that can control the formation of these coalition models and the second part is to the usage of the power control to change the impact of interference of D2D Pairs on the other D2D Pairs.

3.2 Coalition Formation

The following describes the coalition formation procedure.

1. First, the BS presets an SINR value to be satisfied, denoted by $SINR^{th}$. Then, if the D2D pairs interfere with each other, the BS calculates the minimum required transmit power

$P_{min,\ i\ ,\ j}$ for D2D pair i and the minimum required transmit power for D2D pair j, $i \neq j$.

2. Construct a matrix **L**. Check the minimum transmit power of each D2D pair sequentially, if

$P_{min,\ i,\ j}$ is less than the default transmitted power.

3. For D2D pairs i and j, if they belong to a clique, it defines a set **Q**.

4. Check the set **Q** generated in the previous step and select cliques in which all members satisfy the preset $SINR^{th}$ to derive a set **R**.

5. Define the undirected graph **G** = (**V**, **E**), where **V** is the set of vertices, consisting of the members of cliques in the set **R**, and **E** is the set of connections, as illustrated in Fig 2.

6. Use the Bron-Kerbosch algorithm to find maximal cliques of **G**. The time complexity of the algorithm is given in [12].

7. Among the maximal cliques, choose the one with the largest number of unique elements and denote the selected maximum clique as MC_1. The links from MC_1 to the other D2D pairs are removed. This is depicted in Fig 3.

8. Repeat step 7 on the remaining maximal cliques to find the next maximum clique, as shown in Fig 4, until all D2D pairs belongs to one maximum clique. Eventually, a total of **Z** maximum cliques is formed.

9. After completing the steps for finding the maximum cliques, we impose a requirement on the minimum number of members in each maximum clique. Maximum cliques that satisfy the criterion form a set **S2**. Conversely, maximum cliques that do not meet the criterion are dismissed so that D2D pairs originally in them form a set **S1**.

10. The Coalition Formation Algorithm is invoked. First, we choose the appropriate transmit power based on $P_{min,\ i,\ j}$ as shown in lines 8 -10 of the algorithm. Assume each member of the maximum clique transmits with the maximum transmit power and calculate the SINR value accordingly, as shown in lines 12-17 of the algorithm. A member l of **S1** requests to join a maximum clique MC_k in **S2** that meets the condition for all j in MC_k and l is deleted from S1, as shown in line 20 of the algorithm.

11. After the request from the D2D pair l is granted, the SINR is calculated in turn for each member D2D pair in MC_k to determine whether the required SINR is met under the controlled transmit power. If so, accept the D2D pair l as a new member of MC_k; otherwise, reject it. This is shown in lines 21-29 of the algorithm. If a D2D pair fails to join any maximum clique, it forms a clique by itself. The final resulting maximum cliques and the remaining isolated D2D pairs constitute the coalitions.

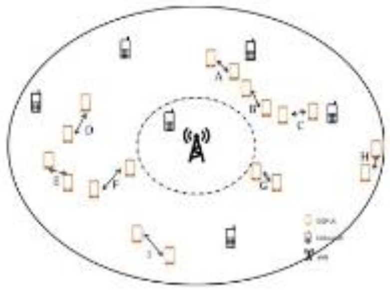


Fig. 1: Coalition Formation

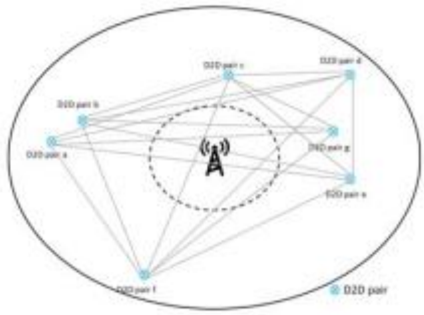


Fig. 2: Undirected Graph of D2D Pairs that Satisfy the SINR Requirement

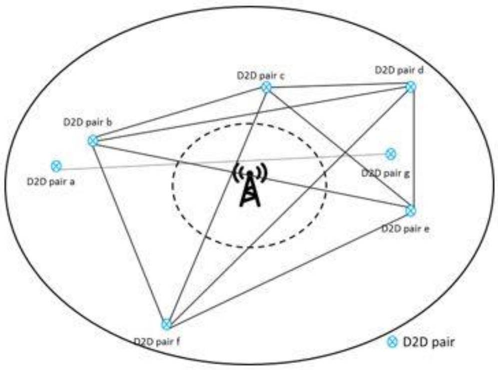


Fig. 3: Determination Of MC_1 and Removal of Links with Other D2D Pairs

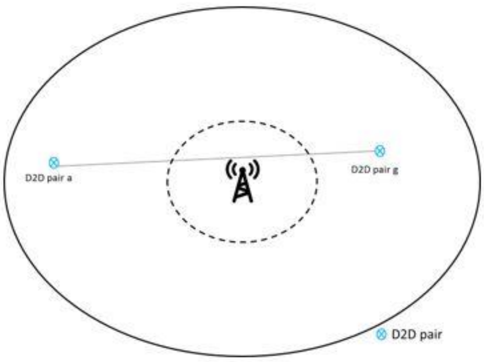


Fig. 4: Determination of Maximum Clique for the Remaining D2D Pairs.

3.3 Coalition Formation Algorithm

1. **#define** S1 = set of isolated D2D pairs
2. **#define** S2 = {MC_1, MC_2, …, MC_Z}
4. **#define** P_n = number of times an isolated D2D pair can adjust the transmit power.
5. **#define** $P_t^{\min}$ a matrix of size $N^D \times N^D$, each row i of the matrix is a descending list of the minimum transmit power of a D2D pair i with respect to the other D2D pairs.
6. counter=1
7. **while** ($S1 \neq \emptyset$ && counter<P_n)
8. **for** j =1:N^D
9. $P_j = P_t^{\min}(j, \text{counter});$
10. **end**
11. H= {1, 2, 3, …, Z}
12 **for** m=1:|$S1$|
13 j=$S1$(m)
14. **for** l=1:Z
15. $I_{l,j} = \sum_{k=1}^{|MC_l|} (I_{k,j} = P_0 / PL_{k,j});$
$$SINR_{l,j} = \frac{P_j / PL_j}{I_{l,j} + \eta}$$
16. **end**
17. **end**
18. **for** m=1:|$S1$|
19. $j = S1(m)$
20 $k = \arg\max_{l \in H} SINR_{l,j}$ s.t. $SINR_{l,j} \geq SINR_{th}$
21. **for** i=1: |MC_k|
22. $SINR_{j,i} = \frac{P_0 / PL_i}{(P_j / PL_{j,i}) + \eta}$
23. **if** $SINR_{j,i} < SINR_{th}$
24. $H = H \setminus \{k\}$
25. break
26. **end**if
27. **end**
28. $MC_k = MC_k \cup \{j\}$
29. $S1 = S1 \setminus \{j\}$
30. **end**
31. counter=counter+1
32. **end while**

4 Proposed Power Control Scheme

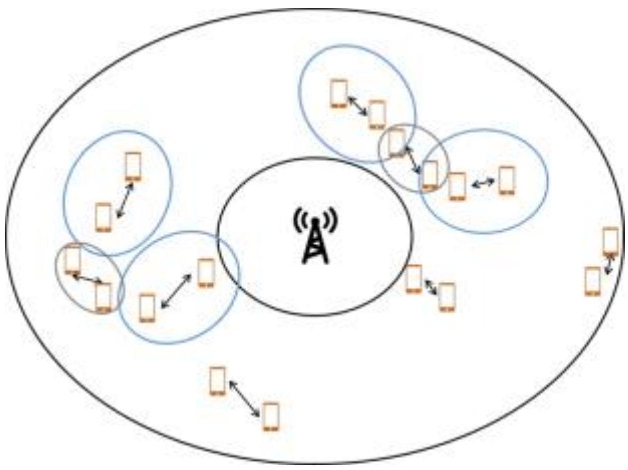


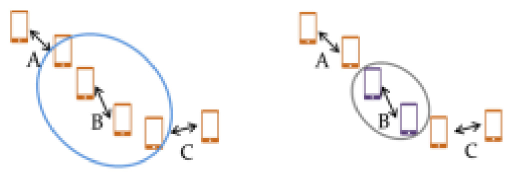
Fig. 5: Power Control Scheme

In fig 5 the blue elliptical circle indicates the coalitions are formed like in a traditional way without any impact of power over the D2D pairs.

In Figs. 5 and 6, the blue elliptical circle indicates the coalition coverage of the DUE under a single BS without the application of power control for the coalition formation. The grey elliptical circle indicates the coalition formation of the DUE on performing power control. We can see that there is a much higher rate of interference among users when the coalition is formed without performing power control compared with the coalition groups formed after performing power control. There are two methods to perform power control.

1) Pair A and Pair C already form the coalition, and Pair B adjusts its transmit power only after finding a suitable coalition.
2) Before the formation of the coalition, pair A, B and C will reduce its own power to a minimum value, and then adjust the to the formation of coalition accordingly.

Method 1



Method 2

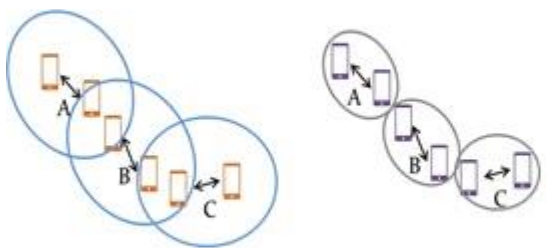


Fig. 6: Coalition formation based on Method 1 and Method 2

4.1 Resource Requirement

Table 1: SINR Corresponding to CQI

CQI index	Modulation	Coding rate	Spectral efficiency (bps/Hz)	SINR estimate (dB)
1	QPSK	0.0762	0.1523	−6.7
2	QPSK	0.1172	0.2344	−4.7
3	QPSK	0.1885	0.3770	−2.3
4	QPSK	0.3008	0.6016	0.2
5	QPSK	0.4385	0.8770	2.4
6	QPSK	0.5879	1.1758	4.3
7	16QAM	0.3691	1.4766	5.9
8	16QAM	0.4785	1.9141	8.1
9	16QAM	0.6016	2.4063	10.3
10	64QAM	0.4551	2.7305	11.7
11	64QAM	0.5537	3.3223	14.1
12	64QAM	0.6504	3.9023	16.3
13	64QAM	0.7539	4.5234	18.7
14	64QAM	0.8525	5.1152	21.0
15	64QAM	0.9258	5.5547	22.7

Table 2: Parametric values to determine RB

CQI	Modulation	Bits/Symbol	REs/PRB	N_RB	MCS	TBS	Code Rate
1	QPSK	2	138	20	0	536	0.101449
2	QPSK	2	138	20	0	536	0.101449
3	QPSK	2	138	20	2	872	0.162319
4	QPSK	2	138	20	5	1736	0.318841
5	QPSK	2	138	20	7	2417	0.442210
6	QPSK	2	138	20	9	3112	0.568116
7	16QAM	4	138	20	12	4008	0.365217
8	16QAM	4	138	20	14	5160	0.469565
9	16QAM	4	138	20	16	6200	0.563768
10	64QAM	6	138	20	20	7992	0.484058
11	64QAM	6	138	20	23	9912	0.600000
12	64QAM	6	138	20	25	11448	0.692754
13	64QAM	6	138	20	27	12576	0.760870
14	64QAM	6	138	20	28	14688	0.888406
15	64QAM	6	138	20	28	14688	0.888406

The Tables 1 and 2 are used to calculate the resource requirements for coalition formation. CQI is Channel Quality Indicator, MCS is Modulation and Coding Scheme, and TBS is Transport Block Size.

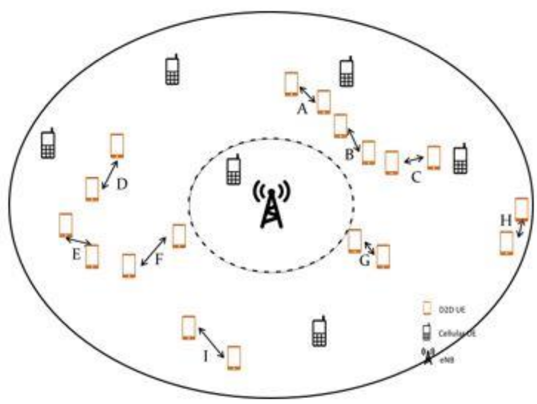


Fig. 7: System Diagram

4.2 Assumptions of the Scenario

- D2D proximity discovery procedure is already performed.
- The eNB knows the position of all the UE's in the environment.
- eNB knows the value of RSRP (Reference Signal Received Power).
- A D2D pair sends its data rate requirement to eNB before their direct communication.
- In D2D, eNB needs to schedules the RB's for the UE to transmit direct data and direct control information.
- All the D2D pairs inform the eNb about their data rate requirements.
- Using RSRP, the eNb calculates how many RB's are needed for the use of each UE.
- With the formation of the coalition, the eNB allocates RB's for the coalitions instead of individually providing to the D2D pairs. This reduces the load on the environment.

We assume that D2D devices are randomly distributed within the coverage of the base station [15]. The proposed method on comparison with [9] is a coalition method that provides a solution of re-using the RB's efficiently. We compute the required number of RB's of a single DUE and obtain the amount of reuse RB's needed. We use the Lookup Table in [10] to compute the rate of RB of an individual D2D pair and compare the total number of reuse RB's and the overall system maximum throughput.

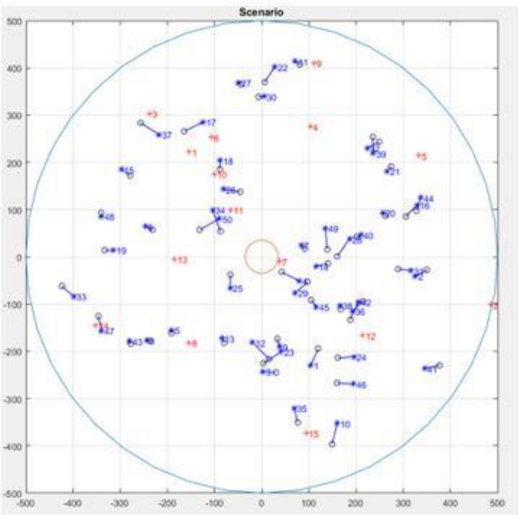


Fig. 8: Layout of a Single Base Station Environment

Fig 8 shows the layout of an individual DUE. The D2D pairs are seen overlapped in the sparse and dense environment, and the distance between the two D2D pairs does not remain the same. First, according to our proposed method, large coalitions cannot be formed because large coalition formation is not the best way of grouping. This is so because there may be an individual D2D pair that does not get included in any of the coalitions. Hence, small coalitions must be formed inside the eNB coverage that allows the efficient reuse of RB's.

Table 3: Parameters Used for Simulation

Parameter	Value
Cell radius	500 m
System bandwidth	20 MHz
Number of D2D Pairs	50
Maximum distance between UEs in the same D2D pair	50 m
Minimum distance between D2D user and eNB	35 m
Minimum SINR between D2D Pairs in the same coalition ($SINR_{th}$)	10 dB
Minimum communicational SINR	-6.7 dB
System bandwidth (uplink)	20 MHz
Range of required Data Rate	0~6 Mbps
Noise spectral density	-174 dBm/Hz

In Fig. 9, we assume that there are two D2D pairs and "d" is the minimum distance between pair A and pair B. we assume that both pairs use 23 dBm to transmit their data and the interference is the same for the two pairs.

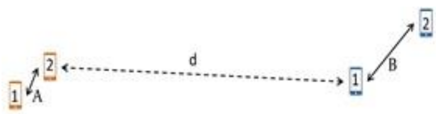


Fig. 9: Scenario for Explaining Power Control

Suppose the two D2D pairs belong to the same coalition. To ensure that the transmissions of A and B will succeed, their SINR should be maintained above a certain threshold. The transmit power of the two pairs will be different because of the different path losses.

4.3.1 Power Control Calculation

$$I_A^D = P_0 - PL_{B,A} \quad (1)$$

- I_A^D is the maximum interference for the D2D pair A.
- P_0 is the default power (23 dBm) of D2D pairs.
- $PL_{B,A}$ is the path loss from UE2 of pair A to UE1 of pair B.

$$SINR_i^d = \frac{P_0 G_{i,i}}{I_i^d + \eta}, I_i^d = \sum_{j=1, j \neq i}^{j=N^d} P_0 G_{j,i} \quad (2)$$

Let $SINR_A^d$ be the SINR threshold for the two pairs in the same coalition.

$$P_{\min,A} = SINR_A^d \left(I_A^d + \eta\right) PL_A \quad (3)$$

- $P_{\min,A}$ is the maximum transmit power of D2D pair A.
- PL_A is the path loss between UE1 and UE2 of pair A.
- η is the thermal noise.
- For different interference, a D2D pair can choose different minimum power levels.

The formula given below is used to calculate the SINR value.

$$SINR_i^d = \frac{P_0 G_{i,i}}{I_i^d + \eta}, I_i^d = \sum_{j=1, j \neq i}^{j=N^d} P_0 G_{j,i} \quad (4)$$

- $SINR_i^d$ is the SINR value of D2D pair *i*.
- P_0 is the default power value of D2D pair *i*.
- $G_{i,i}$ is the gain of D2D pair *i*.
- $G_{j,i}$ is the gain of D2D pair *j* to D2D pair *i*.
- I_i^d is the interference for D2D pair *i*.
- N^d is the number of D2D pair.
- η is the thermal noise.

5 Simulation Results and Analysis

From Fig 10, the formation of the coalition effectively reduces the overall demand of reuse of RB's within a coalition. However, without power control, the number of RB's spent on the system increases, and hence, we need to reduce the power to meet the minimum transmission rate to reduce the use of system resources. By adjusting the power of D2D pairs within members of the same coalition we can decrease interference within the coalition and increase the number of additional RB's [16]. This will improve the overall instantaneous transmission rate.

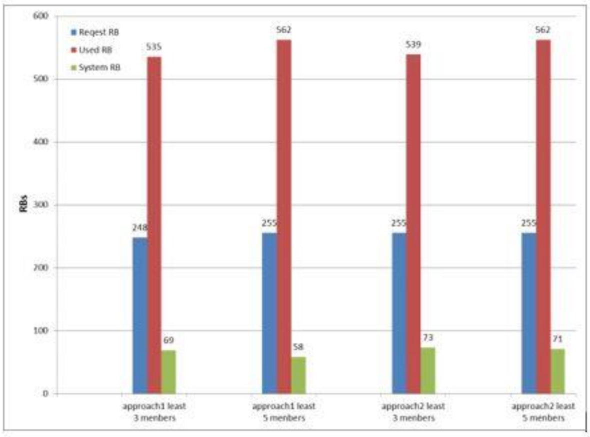


Fig. 10: Total Reuse RB Usage of D2D Pairs

From the result of a single DUE to the formation of a coalition, the comparison shows that DUE's cannot reuse the RB's efficiently if they remain as single pairs. Hence, coalitions must be formed. Here, we set the minimum number of members in a coalition as 5. The simulation was executed 150 times. The bar chart shows the random selection of reused RBs for 150 runs of simulation. The system throughput is thereby determined.

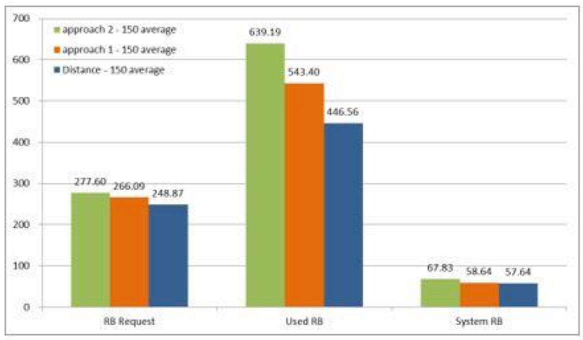


Fig. 11: System Throughput containing Random Access Selection of Reuse RB's

From Fig.11, we can see that the D2D pairs that use three methods have different outcomes for the requirement of the total number of

RB's for each D2D pair. We calculate the reuse RB of each D2D according to the TBS table with respect to the SINR of each D2D pair. The D2D pair with the highest SINR as maximum throughput and will not leave the coalition. The reuse requirement of RB of the D2D pair is maximum as compared to the RB requirement of other pairs inside the coalition. According to this method, a D2D pair that reuses RB's can achieve a maximum throughput of 76%, by using CUE achieves a maximum throughput of 85%, and the throughput is obtained by the location of the D2D pair [9] and by using the system RB's will achieves just a 68% throughput. Despite the enormous increase in the number of D2D users inside the coverage area of the eNB, the system throughput increases because of the formation of the coalition and the reuse of RB's.

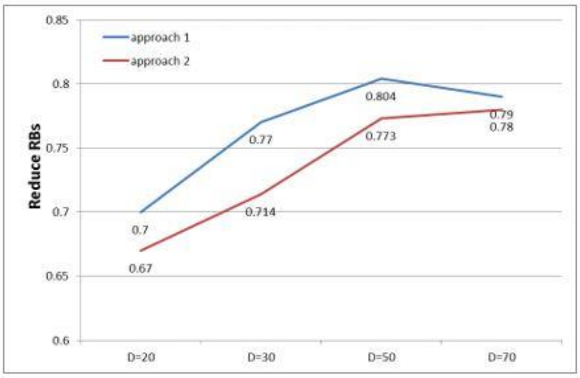


Fig. 12: Effect on the D2D Pairs by the Usage of RB

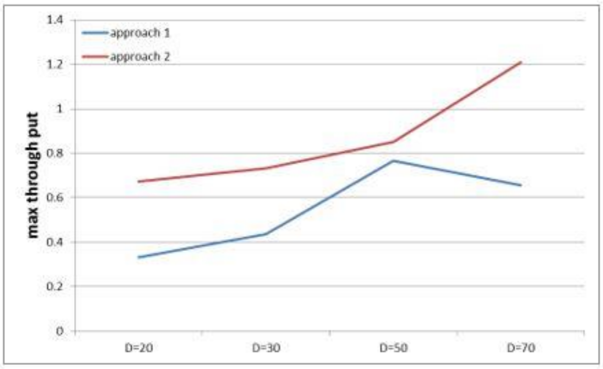


Fig. 13: Maximum Throughput

In Figs. 12 and 13, we see the change in RB usage with the change in the total number of D2D pairs. The horizontal axis D represents the logarithm of D2D pairs, that the system can meet the needs of all RBs. The red line indicates the approach that does not reuse the RBs and the blue line indicates the reuse of RBs by the D2D pairs. From the above graph, we can observe that approach 2 that reuses RBs from the CUE achieve the maximum throughput.

When the threshold SINR is set low, the power required for a D2D pair is low and hence the demand for RB is high. However, when the threshold SINR value is set high, the transmitted power of each D2D pair is relatively high, which in turn affects the members of coalition, Hence, increasing the number of coalitions will result in the maximization of reuse RB's. Therefore, from the above observation, we find that approach two gives a better result.

The simulation of dense and sparse users within the coverage of eNB is shown in Figs. 14 and 15.

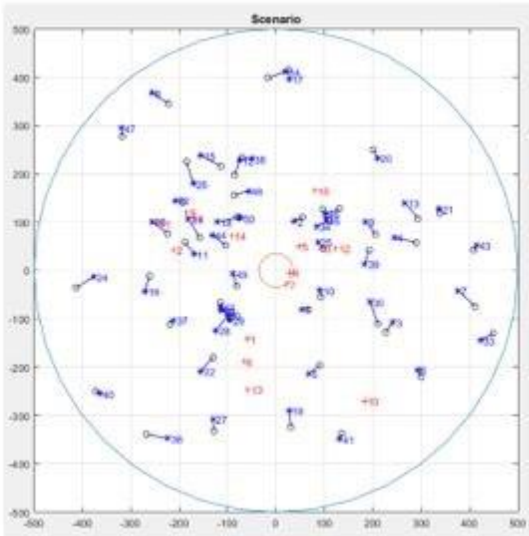


Fig. 14: Simulation Environment with Dense Users

In Fig. 15, the D2D pairs are located far from each other and the distribution of the DUE is uniform. In Fig. 14, the DUE's are located closer to the eNB and the distribution is not uniform. For a densely populated DUE environment, the efficient use of RB's is 79% and the throughput increases by 140%, while in the sparsely populated DUE, the efficient use of RB's is 72% and the throughput increases by 69%. By observing the two conditions, we can see that the distribution in a dense environment achieves better throughput, and the usage of RBs is effective.

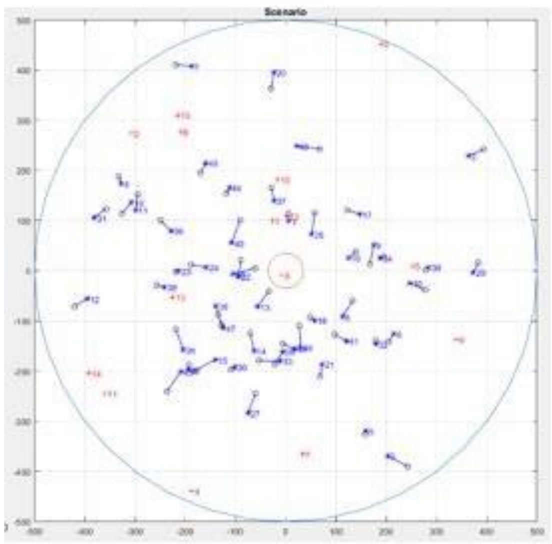


Fig. 15: Simulation Environment with Sparse Users

6 Conclusion

In this paper, the formation of a coalition and power control is used to study the D2D pair within the coverage of eNB. The impact on the usage of resources and their throughput is considered. Simulation results show that changing the power within the members of the coalition, and by the allowance of maintaining a minimum threshold SINR, an increase in the throughput is achieved. In addition, resources are also reused efficiently. For future research, the total amount of data transmitted by the individual UE should be calculated. eNB is expected to meet the demand of every D2D pair. The power control of the UE and the impact on resource allocation may also be considered for greater efficiency.

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